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On the eve of the ECSCRM in Italy it is timely to review some of the progress in SiC materials and devices. The industry has seen some major developments in the past few months. The future for SiC will likely prove as interesting as ever, if recent events are any indication. Nevertheless, while leaders like Cree buck the trend of shifting mass production to SE Asia, there are signs that the ones who are profiting best from wide bandgap materials, currently, are the equipment suppliers.

The SiC success story

The key province for SiC has been LEDs, but this will by no means be its only commercial opportunity. For now, though, if the recent financial results from Cree are an indicator then SiC has already become a multi-million dollar business.

The recent quarterly results showed that Cree's revenues were a record US$91m - the bulk of which comes from LED-related products. From this result some simple arithmetic indicates that the annual market for SiC opto devices will likely reach the third of a billion mark next year. Then if the rate of growth can be sustained a half billion dollar value will be reached before the end of the decade.

Building on its success, Cree is investing on a large scale saying it will spend US$300m on plant and equipment so as to increase manufacturing capacity. It is also transitioning its LED fabrication to 3-inch substrates doubling the number of production chips per wafer. Such measures should keep it ahead of the intensifying competition from SE Asian companies. It also runs in the face of announcements from fellow North American companies looking to export manufacturing and therefore jobs.

Agilent Extra Bright White LEDs - all high brightness lamps for the ESS application are produced in Malaysia, both in Agilent's own facility as well as at a sub-contractor which uses Agilent equipment, materials, processes and specification. Agilent's LEDs have been produced out of Malaysia for the past 20 years, since the Hewlett-Packard days.

Cree's results are an incredible achievement relying as they do almost exclusively on discrete optoelectronic device products. It is comparable to the US$93m reported by TriQuint Semiconductor. However, the comparison is less effective when relative profitability of the companies are examined. While Cree made US$21m from its largely discretes business, TQS scored US$30m profit in the same period from its largely IC business. According to industry tradition, the profit margins for discretes are usually worse than for integrated circuits. This is ironic given both companies' reliance on the handset business - TQS for RF power amplifier products and Cree's backlighting LEDs.

The GaAs giants

In fact Cree outperformed most of the other well known names in the compound semiconductor business. The exceptions are the 'GaAs Giants' Skyworks and RFMD which reached US$166 million and US$207m revenues, respectively. Again this was largely built on the RF amplifier business although SiGe is figuring more strongly in the portfolios of both companies (while GaN and SiC certainly are not at least for now).

The list of financial results has some interesting inconsistencies. In equipment sales some like Aixtron and Veeco did well while others like Riber did not. This in part reaffirms the way the market has come to be dominated by MOCVD driven in large part by the wide bandgap materials. In the latest quarter, 82% of Aixtron's revenue was generated in Asia, with 15% coming from the US and just 3% from Europe. Revenue in the recent quarter was dominated by LED orders which generated sales worth $72.2m, with high-,

mid- and standard-brightness LEDs forming 54%, 40%, and 6% of the revenue, respectively.

Edward H Braun, Veeco's chairman and CEO, commented, "Our second quarter orders of US$124.7m were up 7% sequentially due to strength in both the compound semiconductor/wireless market which was up 31% sequentially and the semiconductor market, up 121% sequentially". This strong performance included US$42.4m in second quarter 2004 orders for the TurboDisc MOCVD products required for HB-LED manufacturing. The latter must be proving the soundness of the decision to acquire this business from the original developer of TurboDisc, Emcore Corp, last November. Veeco paid US$60m in cash for the net assets of the MOCVD business unit of Emcore. The transaction also includes a two-year earn-out feature that would require payment of up to an additional $20m if future revenue targets are achieved. So its success may bring rewards for everyone. To adjudge the importance of these MOCVD sales one only has to look back at Veeco's Process Equipment sales in the first quarter of 2003 which were US$29.6m compared with US$44.8m in the first quarter of 2002.

Veeco Instruments received a US$10m order to supply GaNzilla MOCVD production systems to Lumileds Lighting which is part of a multi-year purchase order for additional systems. The scale of these investments is made even more impressive because only in July Lumileds also signed a 4-year MOCVD systems supply contract with Aixtron AG. This includes a significant number of Aixtron Planetary Reactors for mass production of Lumileds' SiC/GaN-based Luxeon products.

At the time Paul Hyland, president and CEO of Aixtron, said: "This agreement reflects the biggest order Aixtron has taken in its history, made even more significant by Lumileds' leadership position."

SE Asia beckons

Turning now to those all-important developments in SE Asia, Veeco previously gained an order valued 'in excess of US$10m' for several more GaNzilla production systems. The order came from Fujian Quanzhou Sanan Group, one of the manufacturers of HB-LEDs setting up in China.

Curiously, nearly all of the equipment orders are still being shared between just two western companies. With the lack of any eastern equivalent this situation is likely to prevail for the duration. Nevertheless, such orders re-emphasise the growing importance assigned to capturing market share in the HB-LED industry by SE Asia start-ups. This has been growing at a prodigious rate of late, but it remains to be seen how they can succeed given their late arrival and the control exerted by first and foremost the North American companies and secondly the second wave of LED suppliers which has sprung up in Taiwan in the past half-decade or so. Neither of these groups is resting on its laurels, as demonstrated only last month by Taiwanese LED manufacturer South Epitaxy ordering five GaNzilla tools. Whatever the case, a recent report from Strategies Unlimited suggests that manufacturers in the non-Japan region of Asia account for 40% of the world's GaN-based LED chips. So it is all happening in SE Asia and notably in China so the competition will only grow stronger; the question being as to where all this capacity is going to go.

Lumileds, like Cree, seems to be staying loyal to its North American workforce - with such announcements it must be confident that these multiwafer systems can enable it to exert enough leverage to compete against Far Eastern companies. Sadly they too have the funds to make similar investments. So it may come down to who gets theirs up and running first and the quality of the staff running them as to who wins and retains the big production orders for LED chips. Suffice to say most of the back-end processing could well be being outsourced to the Far East.

It would seem that for now western companies are making more money from selling the equipment to make LEDs than from making the devices themselves. This is reminiscent of the story about the Wild West Goldrush; you got rich selling the pickaxes rather than looking for the gold.

Materials mixed

In materials, Soitec was able to report better results, thanks to its newest subsidiary the former GaAs epiwafer pioneer Picogiga. Ironically, it was GaN wafers from Picogiga which contributed so well to the French company's new parent's revenues and not the GaAs HEMTs which used to be its *raison d'etre.* Unfortunately, a company which combines both types of III-Vs, Kopin Corp, has not done so well. It has managed to reduce its quarterly loss, however. It was one of those to report a loss even though its HBT and GaN products have been popular in the market. In contrast to the Cree approach, the manufacture of LEDs in the USA is no longer a viable solution or so said Kopin's CFO Richard Sneider at an investors meeting. From his perspective the Taiwanese "have really gone in and started to slash and burn on the price. It is becoming a pricing-cost game." As a result, Kopin says is looking for a joint venture partner so it can to outsource the more labour-intensive parts of its LED making to Asia. This follows on from the route it took to achieve better cost control for its CyberDisplay product line, for which it partly outsourced production in 2001. Nevertheless, its other III-Vs are yielding better results: "Demand for Kopin's HBTs in the wireless handset and WLAN markets continues to grow. We are currently working to bring additional capacity online," said John Fan, Kopin's CEO. Clearly, the North American companies are going to have to keep on pushing ahead with the introduction of even higher performance products so as to stay ahead, while the SE Asian companies as usual mop up the commodity chips.

SiC wafers

However, other developments are afoot which could serve to limit the future growth of SiC at least in the LED substrate market. Firstly, on the substrate technology side GaN single crystal substrates are emerging and heteroepitaxy of wide bandgap semiconductors on silicon still looks promising. More serious, however, may be the partnerships being set up by Cree's arch-rival, Nichia. The

Japanese company has surprised some market observers over the years. Most recent has been its seeming reversal of policy regarding the sharing of its technology for certain types of LED. Through this means it is effectively going to increase the share of the market because these deals involve epitaxy of III-nitride alloys on sapphire and not SiC. In effect the 'standard' is and will remain GaN-on-sapphire. Moreover, they appear to involve the 'low-end' market. Announcements have included reference to going to China for very high volumes of LEDs for backlighting etc. This is a traditional business re-positioning and is only surprising given Nichia's earlier apparent reluctance to licence its technology. Undoubtedly these devices have become lower margin and logically manufacture should shift to lower cost regions. This is paralleling the laser market whereby CD and DVD laser diodes once made almost exclusively in Japan went to Taiwan and now are headed for PRC. For example, as Japan-based DVD burner makers progress the development of next-generation blue laser models, they will likely place OEM orders for current DVD burner models with Taiwan-based companies. As this market follows the path of DVD players, margins will narrow necessitating economies of scale and this could well include migration of more manufacturing to China.

Coming into play

As all of these trends come into play, Nichia and its fellow Japanese device companies will want to be free to concentrate on next-generation, higher-margin devices such as high brightness white LEDs for backlighting of televisions, Blu-Ray lasers and such. For example, at the Automotive Engineering Exhibition 2004 in Yokohama there was great interest in headlights using white LEDs, providing reduced power consumption for vehicles as the amount of onboard automotive electronics continues to soar. Since LEDs are now commonplace inside and outside vehicles only the headlights are left. In fact, Koito Manufacturing showed a car headlight with 11 LED modules which exceeded 400 lumens in output; somewhat short of halogen or HID headlights but very promising.

Sony is also going to market 40+-inch screen TVs incorporating LED-based backlighting. This follows NEC-Mitsubishi Electronics Display, the producer of flat-panel monitors, unveiling its LCD prototype displays using a system based on Lumileds' Luxeon LED at the Windows Hardware Engineering Conference in May.

Such home entertainment products are critical to these Japanese companies strategic plans to reassert their dominance of the market. Even though they represent major technical challenges and the companies are not alone in the pursuit of them when they come into play over the next five years or so they will decide who the market leaders will be. Underpinning them will be wide bandgap SiC and III-V semiconductor technologies.